PATENT · SPECIFICATION

DRAWINGS ATTACHED

952,752

Date of Application and filing Complete Specification July 31, 1961.
No. 27772/61.
Application made in Germany (No. S69703 VIIIb/21d1) on July 30, 1960.
Application made in Germany (No. S74387 VIIIb/21d1) on June 19, 1961.
Complete Specification Published March 18, 1964.

Index at acceptance:—H2 A(2E9, 8D2)
International Classification:—H 02 k

COMPLETE SPECIFICATION

A Stator Winding in an Electric Machine

We, SIEMENS-SCHUCKERTWERKE AKTIENGESELLSCHAFT, a German Company, of Berlin and Erlangen, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a stator winding in an electric machine. It is especially applicable to a winding for a turbo-generator. In some known constructions of such windings, the conductor bars are formed of hollow component conductors which are transposed according to the Röbel principle and are connected at each end by means of metal caps which permit the passage of the coolant and at the same time effect the electrical connection. The caps are connected to the component conductors in fluid-tight fashion by soldering or welding and are formed with channels or branches for carrying the liquid coolant, for example water or oil. However, such an arrangement is unfavourable in various respects. It involves the use of a relatively large number of connecting caps and line connections, which are very difficult to accommodate by reason of the relatively limited space in the overhang region. In addition, considerable additional losses occur with such a winding construction, one important factor being that the end stray fields of the machine are considerably increased owing to the fact that the current loading capacity is substantially raised by the liquid cooling. Consequently, the additional losses produced by the end stray fields are substantially increased by short-circuit currents. Moreover, the use of a very large number of connecting caps exposed to the stray field results in an increase in the losses.

According to the present invention there is provided a stator winding in an electric machine, wherein each conductor bar consists of individual hollow component conductors which are transposed within the slots and which carry a fluid cooling medium when the machine operates, the winding including a number of sections which are connected in series and each of which consists of a number of turns of the conductor bars, with the component conductors of the different bars connected together in series so that the electric current and the cooling medium may flow successively through them, and wherein within each section the different component conductors of each bar are insulated from one another, both within the slots in the stator and also at the end connections in the overhanging portions of the winding, and wherein at each end of each section, but not within the sections, the different component conductors of the bar which constitutes the end of the section are electrically connected together with the aid of a cap which fits over the end of the bar and which, in addition, is constructed to convey the cooling medium to or from the component conductors of the bar.

For a better understanding of the invention and to show how it may be carried into effect, reference will now be made to the accompanying drawings, in which:—

Figure 1 illustrates diagrammatically in developed form a part of an alternating-current machine, namely the iron laminations of the stator and a stator winding,

Figure 2 shows a cross-section through a composite conductor bar, consisting of several component conductors, of the winding according to Figure 1,

Figure 3 illustrates diagrammatically the arrangement and electrical connection of the component conductors within a winding section,

Figure 4 illustrates the details of the connection of the component conductors of the bars at the connecting points within the winding section,

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Figure 5 illustrates in section the construction of a connecting cap at the connecting and terminal points of the winding section,

Figure 6 and 7 correspond to Figures 1 and 3, respectively, and relate to a further constructional example,

Figure 8 illustrates in perspective the joined ends of two conductor bars within a winding section, and

Figure 9 illustrates a different form of connection of the component conductors of two bars.

Figure 1 illustrates diagrammatically in developed form part of the stator of an electric machine, for example an alternating-current generator, and also shows a winding length for one phase. For the sake of simplicity, the further winding lengths necessary in polyphase machines are not illustrated. The windings constructed as a lap winding and the illustrated winding length is formed of series-connected turns 1 to 4. For the sake of simplicity, only four turns are shown, but of course a larger number of turns per phase could be provided. The individual turns are composed of upper bars 1_o to 4_o and lower bars 1_r to 4_r. The bars are staggered at the periphery of the machine and are connected in the sequence 1_o—1_r—2_o2_r ..... 4_o—4_r.

The terms "upper bars" and "lower bars" designate the positions of the bars in the slots, i.e. whether a bar lies in the upper part or the lower part of the slot. Here, the upper part of the slot is regarded as the part that is nearer the rotor of the machine and the lower part of the slot is the part that is further from the rotor. In Figure 1, the iron body of the stator is denoted by *e* and the slots in which the conductor bars lie are denoted by *n*. Each conductor bar consists of a straight portion lying in a slot of the stator, and the bent over coil end or end overhang portion. The bars are conductively connected together at the ends of the end overhang portions in a manner which is described in greater detail below.

Each individual conductor bar has the cross-section shown in Figure 2 and consists of individual hollow component conductors 1 which are electrically insulated from one another and are juxtaposed in two rows and are transposed or stranded in accordance with the Röbel principle within the straight portion of the bar which lies in slot of the machine, in order to prevent throughout the length of the bars within the iron core of the machine the generation of unequal parasitic voltages by the variable stray field across the slots and thus to prevent the consequent losses due to circulating currents. There is denoted by *h* an insulating sleeve surrounding the composite bar. When the machine is in operation a liquid cooling medium flows through each component conductor.

The illustrated winding length for one phase is subdivided into a number of equal sections, each of which consist of a number of turns. In the example illustrated in Figure 1, the turns 1 and 2 form one section A and the turns 3 and 4 form another section B, the coolant being supplied at *a* and *c* and discharged at *b*. At these points, i.e. at both ends of each of the sections A and B, and only at these points, metallic connecting caps are fitted over the conductor bars.

With the aid of the cap used at the point *a* which is one end of the phase of the stator winding, all the component conductors of the upper bar 1_o, which constitutes one end of the section A and also one end of the phase of the stator winding, are electrically connected together. The cap is constructed to convey the cooling medium to the section A from outside the winding. Likewise, with the aid of the cap used at the point *c*, which is the other end of the phase of the stator winding, all the component conductors of the lower bar 4_r, which constitutes one end of the section B and also one end of the phase of the stator winding, are electrically connected together. This cap is constructed to convey the cooling medium to the section B from outside the winding. With the aid of the cap used at the point *b*, where one end of the section A is joined to one end of the section B, there are electrically connected together all the component conductors of the two bars 3_o and 2_r, which bars constitute ends of the two sections A and B. Thus the two sections A and B are connected in series with the aid of this cap. The cap is illustrated in Figure 5 and discussed below.

Within each of the sections A and B, the component conductors of the different bars are individually connected together in series so that the electric current and the cooling medium may flow successively through them that is to say, for example, one component conductor of the bar 1_o is connected in series with one conductor of the bar 1_r, one conductor of the bar 2_o and one conductor of the bar 2_r, and likewise a second conductor of the bar 1_o is connected in series with a second conductor of each of the bars 1_r, 2_o and 2_r. These connections are effected by soldering or welding component conductors together or in the manner described below with reference to Figure 4.

Within each section, the different component conductors of each bar are insulated from one another, not only within the slots in the stator but also at the end connections in the overhanging portions of the winding. Thus, for example, all the component conductors of the bar 1_o are insulated from one another and so too are all the component conductors of the bar 1_r.

Figure 3 of the drawings diagrammatically indicates the arrangement and connection of

the component conductors of the winding section A formed of the turns 1 and 2. For the sake of simplicity, it has been assumed that each of the conductor bars 1_o, 1_u and 2_o, 2_u forming the turns 1 and 2 is composed of ten component conductors which are arranged to form two rows of component conductors each row consisting of five conductors, within the bars in the usual manner and are transposed or stranded in accordance with the Röbel principle. Within each slot the two rows of conductors forming one conductor bar extend in the direction of the depth of the slot. For the sake of simplicity, only five component conductors of each bar are shown these being the conductors which, at each end of the slot, are arranged in one row. In the upper bar 1_o, the uppermost component conductor is referenced 1_{o1} and the lowermost component conductor referenced 1_{o5}, the component conductors referenced 1_{o2}, 7_{o3} and 1_{o4} occupying intermediate positions between the conductors 1_{o1} and 1_{o5}, in the order indicated by their second numbers 2, 3 and 4. The upper bar 2_o likewise has an uppermost component conductor 2_{o3}, a lowermost component conductor 2_{o5} and intermediate component conductors 2_{o2}, 2_{o3} and 2_{o4}. In contrast to this, in the lower bars 1_u and 2_u the lowermost component conductors have 1 as their second number, for example 1_{u1}, and the uppermost component conductors have 5 as their second number, for example 2_{u5}, with intermediate conductors having 2, 3 or 4 as their second numbers. Where reference is made to uppermost and lowermost component conductors of a bar, it is to be understood that this is only a reference to the positions of those portions of the conductors which are situated at the ends of the slots. Between the ends of each slot the conductors are so transposed, as indicated by sloping lines in Figure 3, that each conductor has parts thereof occupying all five levels in the bar. Each conductor enters the slot at one level and emerges from it at the same level in relation to the top and bottom of the slot.

In Figure 3, a^1 and b^1 denote the connecting caps through which the coolant is supplied to and discharged from the winding section A consisting of the turns 1 and 2. The cap b^1 serves at the same time for the electrical connection of the winding section A to the adjoining winding section B, consisting of the turns 3 and 4 (see Figure 1), and for the discharge of the cooling medium from both sections. The electrical connections between the cap a^1 and the phase terminal of the machine are not shown, nor are the connections for the cooling medium to flow to the cap a^1 and from the cap b^1.

At the connecting points, indicated by X in Figure 3, at both ends of the stator, the component conductors are not all connected together (as perhaps is suggested by the showing of the connections in Figure 3). Instead, an uppermost conductor of an upper bar is connected to a lowermost conductor of a lower bar (for example 1_{o1} to 1_{u1}), a next upper most conductor of an upper bar to a next lowermost conductor of a lower bar (for example 1_{o2} to 1_{u2}) and so on, a lowermost conductor of an upper bar being connected to an uppermost conductor of a lower bar (for example 1_{o5} to 1_{u5}). Thus at each of the connecting points there are five separate connections for the five illustrated components conductors. These five connections are insulated from one another. Figure 4 shows how these connections may be effected as an alternative to welding or soldering them directly together, by U-shaped tube connectors r_1 to r_5 of different base lengths which are pushed over the ends of the component conductors and soldered or welded to them. Figure 4 shows, by way of example, the five connectors between the conductors of the bars 1_o and 1_u.

Figure 5 shows in section the construction of the connecting cap which is used at the connecting point b^1 (in Figure 3) of the winding to connect the ends of the two sections A and B of the winding together. The upper and lower bars 3_o and 2_u have the insulation removed from the individual conductors and the ends of the bars are held within the cap 11 and conductively connected to the cap in fluid-tight fashion. To improve the electrical connection, a sleeve 10 is provided between the cap and the bars. 12 denotes a guiding chamber for the cooling medium within the cap, and 13 a branch for the connection of a liquid-discharge duct 14 (or instead it could be a liquid-supply duct) consisting of insulating material. As is indicated by arrows, the liquid coolant can flow to the supply duct 14 through the coolant guiding chamber 12 from the individual hollow component conductors, all of which are electrically connected together by the cap and by the sleeve 10.

The number of terminal connecting caps and thus of the ducts for supply or discharge of the cooling medium can be effectively reduced by using the connecting caps only at the ends of the sections comprising a number of turns, as described above, while the heating of the cooling medium and the pressure drop within the tubular channels can be kept within low limits.

The described winding can be substantially improved by effecting the connections in a different manner at the central one of the three connecting points X shown in Figure 3.

Figures 6 and 7 illustrate these different connections which are explained in greater detail below. The result obtained by the manner of connecting the component conductors which is shown in Figure 7 is that within each of the sections A and B of the

stator winding the resultant inducted voltage set up between component conductors in one half of the section due to the action of the stray field on the overhanging portions of the winding conductors is connected in opposition to, and substantially cancels out, the corresponding resultant induced voltage set up in the other half of the section. Such an arrangement is more fully described, and is also claimed, in the specification of our co-pending Application No. 21635/60 (Serial No. 952,751). As is shown in Figure 6, connecting loops 8 are provided at the centres of the winding sections A and B. As is shown in Figure 7, the connections at the centre of the section A between the component conductors of the bars 1_U and 2_O are, in contrast to what is shown in Figure 3, upper conductor of upper bar to upper conductor of lower bar, lower conductor of upper bar to lower conductor of lower bar, and so on. Thus the connections are 1_{U3} to 2_{O1}, 1_{U4} to 2_{O2} . . . . . and 1_{U1} to 2_{O3}. The connections illustrated in Figure 7 on both sides of the centre of the section A are the same as those shown in Figure 3 the result of the connections shown in Figure 7 being substantially to eliminate short-circuit or loop currents caused by end stray fields within the winding sections, even if each individual winding section consists of only two turns.

Figure 8 illustrates in perspective the principle of the construction of the connection loop which is used at the point S of Figure 7, which point corresponds to one of the points 8 of Figure 6. In Figure 8 there is actually shown an upper bar 2_O connected to a lower bar 1_U, each bar consisting of two rows of four component conductors, one row being shown to the left at the top of Figure 8 and the other to the right, in the case of each bar. By the connection loop, the component conductors of the left-hand row in the bar 2_O are connected individually to the component conductors of the right-hand row in the bar 1_U. In the connection loop each bar is initially bent over at x about an axis which is parallel to the broad sides of the bars and, further from the slots, the bar is again bent over at y about an axis which is parallel to its narrow sides. After further bent portions, the ends of the component conductors of the two bars abut one another individually and are connected together by hard or soft soldering at t in such manner that the cooling medium channels therethrough are maintained. The upper component conductors of one bar are connected to the upper component conductors of the other bar and the lower component conductor of one bar are connected to the lower component conductors of the other bar, similar connections being established between the other component conductors.

Instead of simply soldering the component conductors together in the connecting loop, there may be provided, at the connecting point t, narrow pushed-on tubes t_1 which are hard-soldered or soft-soldered to the component conductors, as shown in Figure 9.

The example illustrated in Figures 1 and 3 may be modified by arranging for each winding section to have an odd number of conductor bars, i.e. an integral number of turns plus half a turn (for example $3\frac{1}{2}$ or $4\frac{1}{2}$ turns). In this case, the connecting caps lie on alternate sides of the winding, i.e. at alternate ends of the stator.

WHAT WE CLAIM IS:—

1. A stator winding in an electric machine, wherein each conductor bar consists of individual hollow component conductors which are transposed within the slots and which carry a fluid cooling medium when the machine operates, the winding including a number of sections which are connected in series and each of which consists of a number of turns of the conductor bars, with the component conductors of the different bars connected together in series so that the electric current and the cooling medium may flow successively through them, and wherein within each section the different component conductors of each bar are insulated from one another, both within the slots in the stator and also at the end connections in the overhanging portions of the winding, and wherein at each end of each section, but not within the sections, the different component conductors of the bar which constitutes the end of the section are electrically connected together with the aid of a cap which fits over the end of the bar and which, in addition, is constructed to convey the cooling medium to or from the component conductors of the bar.

2. A winding according to claim 1, wherein where the ends of two sections are electrically connected together, this is effected with the aid of a single cap which fits over the ends of both the bars constituting the ends of the sections, and also with the aid of this cap there are electrically connected together all the component conductors of both bars, the cap also having a branch for conveying the cooling medium to or from the two sections.

3. A winding according to claim 1 or 2, wherein in each of said sections the hollow component conductors of the different conductor bars are so electrically connected that the resultant induced voltage set up between the component conductors in one half of the section due to the action of the stray field on the overhanging portions of the winding conductors is connected in opposition to, and substantially cancels out, the corresponding resultant induced voltage set up in the other half of the section.

4. A winding according to any preceding claim, wherein each winding section consists of two turns.

5. A winding according to claim 1 or 2, wherein each winding section consists of an integral number of turns plus half a turn and the aforementioned caps lie on alternate sides of the winding.

6. A stator winding in an electric machine, substantially as hereinbefore described with reference to Figures 1 and 3 or Figure 6 and 7 of the accompanying drawings.

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Leamington Spa: Printed for Her Majesty's Stationery Office by the Courier Press.—1964.
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.

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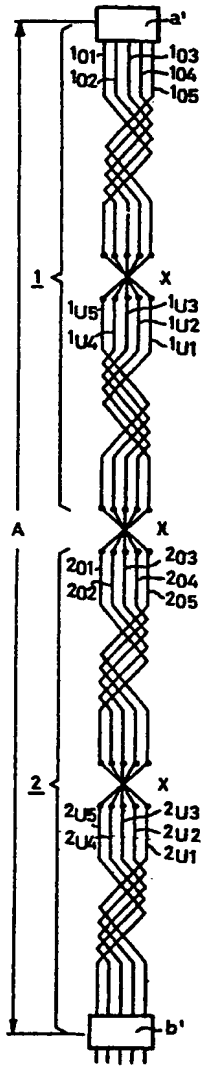

Fig. 3

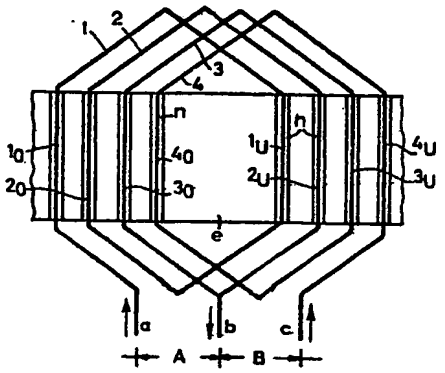

Fig. 1

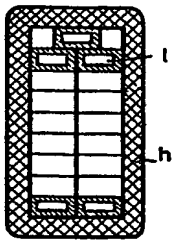

Fig.2

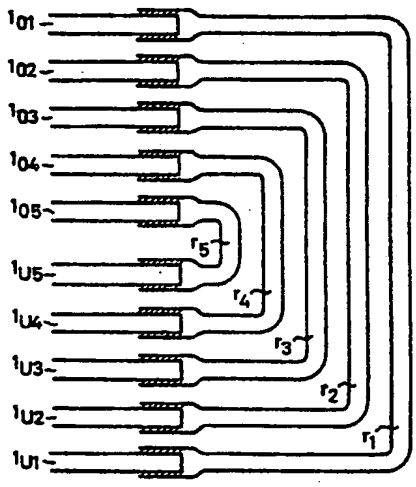

Fig. 4

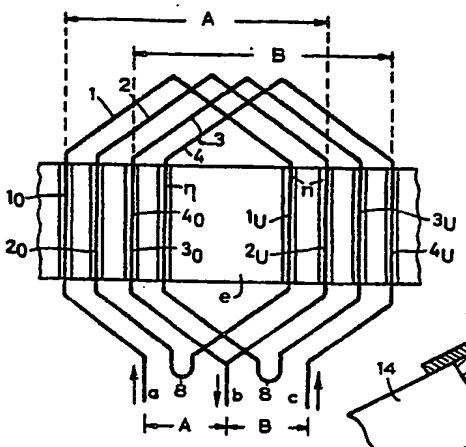

Fig. 6

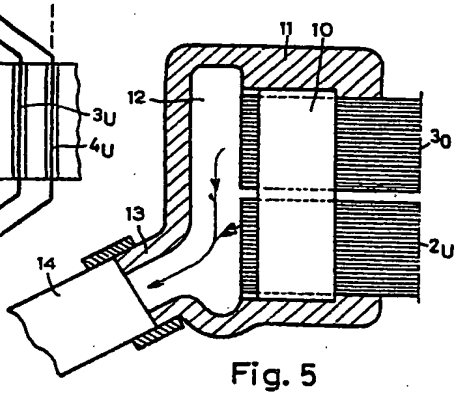

Fig. 5

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Fig. 4

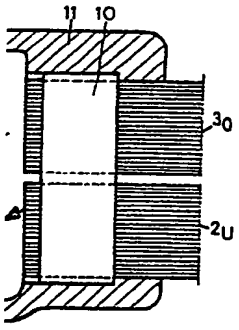

Fig. 5

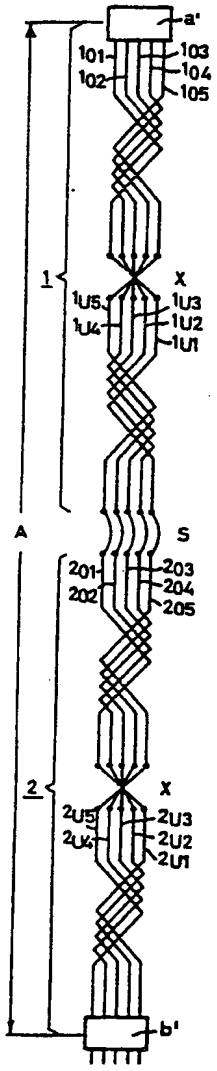

Fig. 7

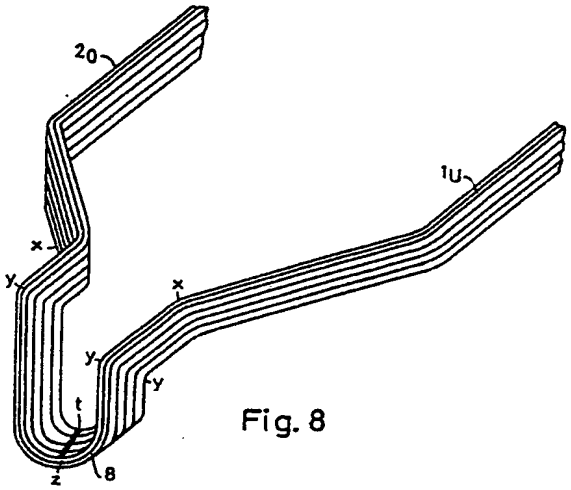

Fig. 8

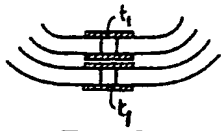

Fig. 9

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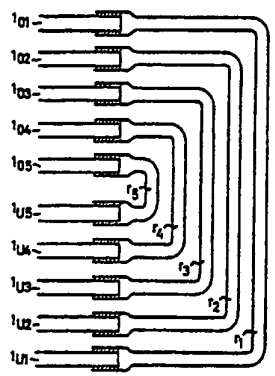

Fig. 4

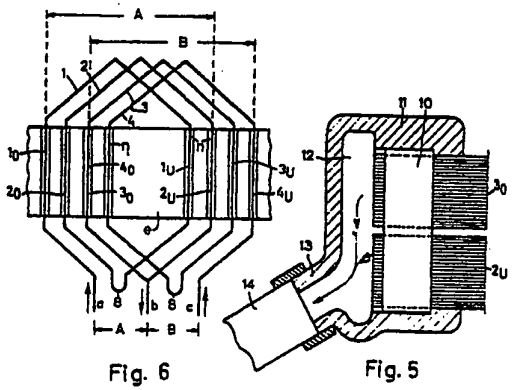

Fig. 6

Fig. 5

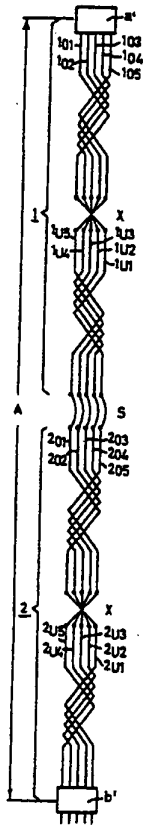

Fig. 7

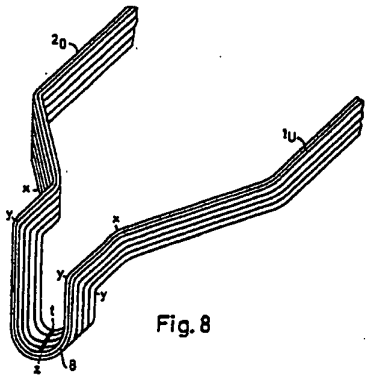

Fig. 8

Fig. 9

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